CLAIMS

[Claim(s)]

1. Magnetic-reluctance device characterized by making at least one side of aforementioned ferromagnetic material layers into product made from semimetal material in magnetic-reluctance device equipped with two ferromagnetic material layers by which mutual alienation is carried out by at least one insertion layer made from non-magnetic material.
2. Magnetic-reluctance device given in claim 1 characterized by constituting two aforementioned ferromagnetic material layers mainly from semimetal material.
3. Claim 1 characterized by making aforementioned semimetal material into metallic oxide, or magnetic-reluctance device given in 2.
4. Magnetic-reluctance device given in claim 3 characterized by choosing aforementioned semimetal material from Fe_3O_4, group formed of CrO_2, and its mixture.
5. Magnetic-reluctance device given in any 1 term of claims 1-4 characterized by using aforementioned non-ferromagnetism material as electric insulation object.

6 The magnetic head which equips any 1 term of claims 1-5 with the magnetic-reluctance device of a publication.

7. Body structure characterized by making at least one of the aforementioned ferromagnetic material layers into product made from semimetal material in structure of body equipped with at least two ferromagnetic material layers estranged mutually by at least one insertion layer made from non-magnetic material.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
The magnetic head using a magnetic-reluctance device and the device of **** this invention relates to a magnetic-reluctance device equipped with two ferromagnetic material layers in which mutual alienation is carried out by at least one insertion layer made from a non-magnetic material.
this invention relates also to the magnetic head which uses the device of ****.
The phenomenon in which it is influenced by existence of the magnetic field to which the electric resistance value measured along the predetermined path in material with suitable magnetic reluctance crosses the material is accepted. therefore, ** -- it can utilize for changing change of a verification magnetic field into resistance change to which it corresponds in material, and a phenomenon [like] can apply the phenomenon itself to a magnetic field sensor and the magnetic head
** -- the magnetic head [like] is used for the data transfer to a magnetic tape or the magnetic-recording medium like a disk, and data transfer from it
The size of the magnetoresistance effect along the predetermined path in a certain specific material is expressed by the following formulas.

$$MR = \frac{(R_L - R_S)}{R_L}$$

They are the maximum from which RL and RS may be measured along the aforementioned path here in an adjustable magnetic field at predetermined temperature, respectively, and the minimum electric resistance value. The value of MR is usually expressed with percentage, and for a sensor use which was mentioned above, enlarging is suitable for it as this value can make it possible to attain optimum sensitivity.
The magnetoresistance effect in a layer structure can be investigated using at least two measuring methods. The 1st measuring method is a measuring method which measures the electric resistance value of a device using the method of impressing voltage inclination in the almost parallel direction to the flat surface of each composition layer of a magnetic-reluctance device and which passes the so-called current at the flat surface of the same method (Current In Plane (CIP)). The 2nd measuring method is a measuring method which measures the electric resistance value of a device using the method of impressing voltage inclination in the almost perpendicular direction to the composition layer of a device and which passes the so-called current perpendicularly to a flat surface (Current Perpendicular to Plane (CPP)). In the case of a predetermined device, the magnetoresistance effect generally measured using a CPP measuring method is larger than what is measured using a CIP measuring method about 3 times. About this, the metaphor is explained in full detail GijS in the 3343-3346th page of Phys.Rev.Lett.70 (1993) outside by the paper by one person.
The three-layer structure of the kind stated at the beginning is suitable to utilize the so-called spin-bulb magnetoresistance effect it is accepted to be to be influenced by the relative magnetization direction (net) of a ferromagnetic material layer whose specific resistance value of this layer structure is two. It is suitable for the layer structure in this case to take shape so that this relative direction can be easily changed using an external magnetic field. Such an example can be attained by at least three following different methods.
(a) Two ferromagnetic layers cross the insertion layer of non-ferromagnetism, and it is combined in antiferromagnetism, and the magnetization direction (net) of a ferromagnetic layer has no external magnetic field, and can serve as antiparallel mutually. In this case, the magnetic field impressed in parallel to the magnetization direction of one ferromagnetic layer can reverse the magnetization direction of the ferromagnetic layer of another side, and can be used for making both magnetization directions parallel mutually.;
(b) One ferromagnetic layer exchanges to the antiferromagnetism bias layer which exists additionally. - Bias is carried out (exchange-biased) and magnetization of the ferromagnetic layer of another side can be turned to the magnetization direction of the aforementioned exchange bias layer, antiparallel, and one of parallel direction modes independently by the external magnetic field.;
(c) Two ferromagnetic layers are realizable so that it may have remarkably different magnetic-saturation holding power. This can be attained by adding the suitable foreign matter with which concentration differs into the material of for example, each ferromagnetic layer. In this case, by using the magnetic field of the intensity selected suitably, even if it does not change the magnetization direction in a ferromagnetic layer with high magnetic-saturation holding power, magnetization of the low ferromagnetism layer of magnetic-saturation holding power can be turned in another direction.

The magnetic-reluctance device of the kind stated at the beginning is explained to the paper by Nakatani and Kitada in the 827-828th page of Mat.Sci.Lett.10 (1991). In this conventional device, 2O3 layers of insulating aluminum are electrically inserted between two ferromagnetic Fe layers magnetized at the flat surface of the same direction, and the electric resistance effect of this combination object is measured using a CPP measuring method. The 1.7 atom % dope of Ru is done at one Fe layer, and the Fe is made to reduce the magnetic-saturation holding power of Fe layer of another side by doing the 2.0 atom % dope of C to increasing the magnetic-saturation holding power. Therefore, the three-layer structure obtained in this case is the thing of the type (c) mentioned above. It is [whether the thickness of 2O3 layers of aluminum to insert is slight, and] 10nm although each thickness of doped Fe layer is 100nm. Such a thin insulating layer acts as a tunnel obstruction between conductive Fe layers which carry out a boundary to this. Even if a

lot of layer material for putting in another way is an insulator, it is sufficient thinness for the thickness of this layer itself to cross the layer, and for most number of electrons pass it statistically.
The electrical resistivity value by CPP of this conventional three-layer device serves as the minimum, when the magnetization direction of the net of two Fe layers to dope is mutually parallel, and when these two magnetization directions are antiparallel, it serves as the maximum. It is the conductance (G) Slonczewski explains the tunnel operation of such a spin dependency to the 6995-7002nd page of Phy.Rev.B39 (1989) in detail, and according to the CPP measuring method of three layers here.
If the relation of the ****** following formula is satisfied, it has come to a conclusion (page [7000th] formula (6.1)).
G=Go (1+epsiloncostheta)
Go and epsilon are constants (epsilon< 1) here, and theta is the degree of same direction plane angle between two magnetization vectors (net) of a ferromagnetic layer. Therefore, few differences with the conductance of three layers of an antiparallel magnetization mode serve as mutually parallel conductance of three layers of a magnetization mode with 2epsilon.
The fault of the tunnel effect of a spin dependency which has constituted the foundation of the conventional device has the value of epsilon in it being general very small. Therefore, the magnetoresistance effect by the CPP measuring method in the ordinary temperature in a device is only about 1.0% conventionally [this]. Such a low value has greatly restricted the sensitivity of the potential magnetic field sensor using the conventional device.
Other conventional spin-bulb (spin valve) magnetic-reluctance devices are indicated by the U.S. patent US 5,134,533, they cross Cr, V, or the insertion layer made from a conductive non-ferromagnetism material like Ti, combine in antiferromagnetism the ferromagnetic material layer like Fe and Co which are in the flat surface of the same direction in this case, or nickel, and form mutual multilayer arrangement equipped with two or more three layer structures of basic of a type (a) mentioned above. Also in this case, electrical resistivity serves as the minimum value, when the magnetization direction of the net of two ferromagnetic layers is mutually parallel, and when these two magnetization directions are antiparallel, it presents maximum.
The magnetoresistance effect in this 2nd conventional device is produced by the scattering phenomenon of a spin dependency, and the degree on which the conduction electron by this phenomenon is scattered within a device is determined by the direction of the intrinsic spin of the conduction electron relevant to the magnetization direction of a ferromagnetic layer. One person is explaining such an effect to the 2472-2475th page of Phy.Rev.Lett.61 (1988) in detail Bailich outside. it is completely small, therefore as for the magnetoresistance effect by CIP in the ordinary temperature of this 2nd conventional device, the size of the magnetoresistance effect in this case is not boiled small about 10%, either, and ** does not have it
The purpose of this invention is to offer the magnetic-reluctance device which presents the far big magnetoresistance effect rather than being obtained by the conventional device.
Other purposes of this invention can present far bigger electric resistance than the conventional device which the configuration and the size resemble, and are to offer the magnetic-reluctance device which reduces power consumption compared with the conventional device by this.
It is characterized by making at least one side of the aforementioned ferromagnetic material layers into the product made from semimetal material in attaining these purpose and other purposes in the magnetic-reluctance device of the kind stated at the beginning according to this invention.
There is the so-called HYU slur (Heusler) alloy which has the constituent XMnZ which uses X as the element like Cu, nickel, Pt, Pd, Co, or Fe, and uses Z as the element like Sb, Sn, In, or Ga as an example of semimetal material, or X2MnZ. As other examples of semimetal material, there are Fe 3O4, and CrO2 and KCrSe2. Each material of these examples is ferromagnetism. Otherwise much material of **** is known and regarding it as the semimetal material which also applies such a thing to this invention is not saying.
The electron which the conduction electron in a ferromagnetic metal can be classified to two independent spin states, and these electrons that have parallel intrinsic spin to the magnetization direction of local net are called a "spin-rise" electron, and has antiparallel intrinsic spin to the magnetization direction of local net is called the so-called "spin-down" atom. In the case of the special case of semimetal ferromagnetism material, the calculated value of a band structure presents a remarkable inequality between such a spin-rise state and a spin-down state. the band to the electron of one spin state -- Fermi level -- crossing -- this Fermi level -- a non-zero state -- existing -- therefore, ** -- an electron [like] may function as conduction electron However, the band to the electron of other spin states has a prohibition energy band in a Fermi level, the density of the state of the neighborhood is zero, therefore these electrons cannot function as conduction electron (low energy). Consequently, semimetal material acts as a semiconductor (insulator) to the electron of the spin state of ** and another side which acts as a metal to the electron of one spin state. That is, spin polarization of the conduction electron in semimetal material is carried out 100%.
Based on the phenomenon stated for the protomerite, the resistance effect of very few spin dependencies currently utilized for the conventional device mentioned above in practice becomes an immense size by using a semimetal for the magnetic-reluctance device by this invention.
The three-layer structure of the aforementioned type (a), (b), or (c) into which two pure layers made from semimetal ferromagnetism material are made to divide by the insertion layer made from non-ferromagnetism material can be used for acquiring the immense spin-bulb magnetoresistance effect. In for example, the case of a CPP measuring method: If the magnetization vector of (1) ferromagnetism layer is mutually parallel, the layer of these both sides will act as a metal to the electron of a predetermined spin state (in Fe 3O4 (for example, this), it is in a spin-down state). Therefore, although the electron of this special spin state crosses the three whole layer perpendicularly mostly and progresses, the electron of a reverse spin state does not serve as this so. Originally the electric resistance in the case of the former is determined by the insertion layer thickness and the quality of the material of non-ferromagnetism.
(2) If the magnetization vector of a ferromagnetic layer is antiparallel mutually, although one side of these ferromagnetism layer will act as a metal to the electron of each spin state, another side will act as an insulator. Therefore, in this case, neither of the electrons of the spin states can cross three layer of the whole perpendicularly mostly. Therefore, originally the electric resistance measured serves as an infinite size.
(3) Few electron flows are made [always running through the whole three layer structure regardless of the magnetization mode of a three layer structure, or] statistically. Furthermore, a spin-flip-scattering event is also produced in the inserted non-ferromagnetism layer, and, thereby, the spin state of a little dispersion atom is reversed. When it receives a spin-flip, in the case of the antiparallel magnetization mode (in the case of (2) mentioned above) in a

three-layer structure, the electron which already crossed one ferromagnetic layer can also pass the 2nd a little more than magnetic layer, and the little leakage current will produce it by this in it. however, the thing for which the non-ferromagnetism layer to insert is relatively made thin -- ** -- generating of a spin-flip [like] can be suppressed to the minimum Furthermore, the tunnel event which runs three layer of the whole through a ferromagnetic layer by thick waste ****** relatively can be suppressed. Originally the magnetoresistance effect of three layers in this case is 100%.

When a ferromagnetic layer was accepted partially and constituted from semimetal material, without constituting the ferromagnetic whole layer from semimetal material, as it is, the size of the magnetoresistance effect observed was reduced.

The suitable example of the magnetic-reluctance device by this invention constitutes both ferromagnetic layers mainly from semimetal material. "said here -- " should mainly understand it as what is used in the implications which show that it is said that other matter which constitutes the ferromagnetic whole layer from semimetal material, is intentionally added to semimetal material, or exists originally may recognize little existence comparatively For example, various little addition of various foreign matters can be carried out at a ferromagnetic layer so that those magnetization properties may be affected intentionally. Especially, the foreign matter like nickel, Co, Mn, Zn, Cu, and Mg is added in a ferromagnetic layer, and those magnetic-saturation coercive force can be changed. In this case, it is not necessary to make composition of two ferromagnetic layers the same natural, and it can consist of different semimetal material.

Of course, multilayer arrangement can be carried out combining some three-layer structures by this invention. The three-layer structure by this invention and the conventional three-layer structure are also combinable together. Furthermore, **** addition layers, such as an oxidization obstruction, the electric contact layer, an insulating layer, and an exchange bias layer, can also be prepared in the magnetic-reluctance device by this invention in addition to three layers of foundations. As the magnetic-reluctance device by this invention prepares one or more insertion layers of non-ferromagnetism between continuous ferromagnetic layers, it is also realizable.

Let semimetal material be a metallic oxide in the suitable example of the magnetic-reluctance device by this invention. Such a material is deposited by for example, oxidization vacuum deposition, oxidization spatter deposition, or oxidization laser ablation (ablation) deposition, and is suitable for evaporation, a spatter, or making it ablate in an oxidizing atmosphere in a pure metal or a metal alloy. Especially the advantageous metallic oxides in this category are Fe3O4, CrO2, and its mixture. Such material is the oxides of the element which usually exists, and can deposit Fe, Cr, or a FeCr alloy evaporation, sputtering, or by ablating.

It is a magnetic-reluctance device by this invention, especially non-ferromagnetism material is used as an electric insulation object in a suitable example. in addition, a lot of [the "insulator" used here] non-magnetic materials -- un--- ** which presents the electric resistance property of a conductor, and when it fully realizes by the film, that (a layer -- receiving -- an almost perpendicular direction) through which a tunneling electron can pass comparatively easily shall be meant It is suitable for such an insulator to present the electric resistance more than 0.01ohmm in ordinary temperature, and it is suitable for this to form in the layer whose thickness is 0.5-10nm. There are GdO, MgO, MgAl 2O4, and SrTiO3 in the example of the suitable electric insulation object for this purpose in a number of large number.

The device of **** utilizes the tunnel process which results in the electronic state (empty) in the opposite side of an obstruction which can be used from the electronic state which occupies one side of the tunnel obstruction of non-ferromagnetism. When an obstruction is sufficiently thin, a transfer of the electron from one ferromagnetic layer to the next ferromagnetic layer is determined only by being based on the electronic state in these two layers, and, originally this is unrelated to the obstruction itself to insert. such an independence does not necessarily become such, when the non-ferromagnetism material to insert is a conductor (for example, Cu, Au, Cr, and LiTi 2O4 -- like) However, if the material of a ferromagnetic layer and the insertion conductor layer of non-ferromagnetism is adjusted suitably, the device by this invention equipped with such a conductor layer can also enlarge the magnetoresistance effect extremely.

Easy explanation of a drawing Drawing 1 and drawing 2 are the cross section showing a part of magnetic-reluctance device by this invention.;

Drawing 3 and drawing 4 are the cross section showing a part of other examples of the magnetic-reluctance device by this invention.;

Drawing 5 is the perspective diagram showing a part of magnetic head using the magnetic-reluctance device by this invention.

The 1st example Drawing 1 and drawing 2 show a part of cross section which cut perpendicularly an example of the magnetic-reluctance device 1 by this invention to the composition layer of this device. The same reference mark is given to what shows the same portion, and both [these] drawings have shown.

First, the insulating NiO antiferromagnetism bias layer 5 is electrically formed on the substrate 3 of MgO. Subsequently, the three-layer structure 7 is located on this bias layer 5. two with this thin three-layer structure 7 electrically estranged by the insulating non-ferromagnetism GaO layer 13 -- electric -- conductive semimetal ferromagnetism -- it constitutes from 9 and 11 3O3 layer of Fe(s) 9 is exchanged to the NiO layer 5 3O4 layer of Fe(s). - Since bias is carried out, the three-layer structure 7 is the thing of the aforementioned type (b). Each magnetization directions M9 and M11 of layers 9 and 11 are in the flat surface of the same direction. The three-layer structure 7 of illustration is crossed and the voltage inclination V is mostly applied perpendicularly so that the electric resistance value of the three-layer structure 7 may be measured using a CPP measuring method. Two electrons 15 and 17 which have the spin 19 and 21 of a retrose (respectively) are also shown in both drawings.

Drawing 1 showed the parallel magnetization mode observed when an external magnetic field is lost, and the magnetization directions M9 and M11 have turned to the same direction in this case. In this magnetization mode, the layer structure 7 acts as a conductor from the following reason.

From the spin 19 of an electron 15 being parallel to the both sides of M9 and M11, layers 9 and 11 act [as opposed to / this electron / in both sides] as an electric insulation object (spin-rise state). However, since the both sides of layers 9 and 11 act from it being antiparallel (spin-down state) as a conductor to this electron to the both sides of M9 and M11, an electron 17 can run through an obstruction 13 and the spin 21 of an electron 17 can pass the layer structure 7 whole in the almost perpendicular direction to layers 9 and 11. In this case, the CPP electric resistance value of the layer structure 7 which can be set is low, for example, are 10-100ohm.

In drawing 2 , the suitable external magnetic field H was impressed to antiparallel to M9. This external magnetic field H is taken as intensity sufficient without changing the direction of M9 to reverse the direction of M11.

Layers 9 and 11 are made into an antiparallel magnetization mode by carrying out like this. In this state, the layer structure 7 acts as an electric insulation object, considering the following reason.
Since 21 is antiparallel (spin-DANU state) to the spinM9 of this electron, an electron 17 can exist as conduction electron within a layer 9. Therefore, an electron 17 can pass this layer 9 in the almost perpendicular direction to a layer 9. However, since 21 is parallel (spin-rise state) to the spinM11, an electron 17 cannot act as conduction electron within a layer 11. Therefore, a layer 11 acts as an electric insulation object to an electron 17. Consequently, an electron 17 cannot pass the layer structure 7 whole perpendicularly mostly.
Having mentioned above and the same thing can say also about an electron 15, a layer 9 acts as an insulator in this case, and a layer 11 comes to act as a conductor. Therefore, in this case, the CPP electric resistance value of the layer structure 7 becomes infinite originally.
The size of the CPP magnetoresistance effect in this example was 100% in practice.
The 2nd example Drawing 3 and drawing 4 show a part of cross section which cut perpendicularly the magnetic-reluctance device 2 by this invention to the composition layer of this device. The same reference mark is given to what shows said 11 portions in both [these] drawings, and it is shown.
the substrate 4 of MgO -- un--- the multilayer structure 6 which consists of the semimetal ferromagnetism layers 8 and 10 which inserted the thin insulating layer 12 of ferromagnetic MgO, and were accumulated by turns is formed A layer 12 acts as a tunnel obstruction between the continuation layers 8 and 10. Although a layer 8 is constituted from Fe 3O4 pure originally, a layer 10 consists of Fe(s) 3O4 lightly doped by Co0.012Fe 2.988O4, i.e., Co. Fe 3O4 -- ** -- since magnetization of Fe 3O4 softens remarkably by adding Co in an amount [like], a layer 10 is softened more magnetically than a layer 8 Therefore, the multilayer structure 6 accumulates two or more three layer structures 14 of basic of the type (c) mentioned above, and is constituted. The magnetization direction of layers 8 and 10 is in the flat surface of the same direction, and has shown these magnetization directions by arrows M8 and M10, respectively. The electric resistance value of the multilayer structure 6 is measured using a CPP measuring method.
Drawing 3 does not have an external magnetic field and a magnetization mode in case the magnetization directions M8 and M10 align in parallel mutually is shown. In the case of this magnetization mode, a structure 6 acts as a conductor.
In drawing 4 , external-magnetic-field H' is applied to antiparallel to the magnetization direction M8. Let the direction of ** aligned by the direction where the size of magnetic field H' has the magnetization direction M10 parallel to magnetization M8, and magnetization M8 be the size which holds the original direction. In such an antiparallel magnetization mode, the layer structure 6 acts as an insulator.
The CPP magnetoresistance effect of a device 2 was 100% in practice.
The 3rd example Drawing 5 is the outline perspective diagram showing a part of magnetic head 31 equipped with the magnetic-reluctance device 33 by this invention with the electric lines or cable 35. this magnetic head 31 is equipped also with the substrate 37 made from a non-magnetic material which deposited the magnetic material layer (NiFe -- like) on the magnetic material (a ferrite -- like) or the top The magnetic head 31 is equipped also with the flux guides 39 and 41 further positioned to the magnetic-reluctance device 33 and a substrate 37 so that a magnetic path may be formed. The end faces 43 and 45 of a substrate 37 and a flux guide 41 constitute a part of pole side of the magnetic head 31, and a magnetic gap 47 is located among these end faces 43 and 45.
When a magnetic tape or the magnetic medium like a disk approaches these and passes through an end-faces 43 and 45 front, adjustable magnetic flux is generated in the magnetic path which the information magnetically memorized to the aforementioned medium mentioned above, and this magnetic flux comes to flow also to the magnetic-reluctance device 33. The magnetic-reluctance device 33 can change this adjustable magnetic flux into an electric resistance change, and can measure such resistance change through an electric lines or cable 35.
An electric coil can also be prepared in the magnetic head and this coil can be used for recording magnetic information on a magnetic medium.
the 4th example Besides the ability to use for a magnetic field sensor (the magnetic head -- like), the magnetic-reluctance device by this invention is also especially applicable as an electric relay as an electric switch. For such a use, in order to change an electric operation of a magnetic-reluctance device, an external magnetic field is intentionally applied to this magnetic-reluctance device. for example, a means to generate a magnetic field (for example, to pass an electric coil) in good control at a magnetic-reluctance device -- preparing -- subsequently -- ** -- a magnetic field [like] is called to predetermined time, and the current which flows to a device can be controlled the suitable current for the conductor (a coil, a loop wire, and a straight wire -- like) which approached the device and was positioned especially can be passed, and the magnetization mode of a device can be changed in good control using the magnetic field generated by this energization, therefore a device can be switched between a high resistance state and a low resistance state The device in such an example can be used as an electric relay.

[Translation done.]